CLIMATE CHANGE, AGRICULTURE AND WETLANDS IN EASTERN EUROPE: VULNERABILITY, ADAPTATION AND POLICY

ELLEN KRACAUER HARTIG
Center for Climate Systems Research, Columbia University, and Stone & Webster Environmental Technology & Services

OGNYAN GROZEV
Forest Research Institute, Bulgarian Academy of Sciences

CYNTHIA ROSENZWEIG
NASA/Goddard Institute for Space Studies, and Center for Climate Systems Research, Columbia University

Abstract. Naturally-occurring wetlands perform such functions as flood control, pollution filtration, nutrient recycling, sediment accretion, groundwater recharge and water supply, erosion control, and plant and wildlife preservation. A large concentration of wetlands is located in Eastern Europe. A significant amount of Eastern European wetlands has been converted to agricultural use in the past, and remaining wetlands are subject to agricultural drainage. Drained wetlands are used as prime agriculture lands for a variety of food crops. Other agricultural uses of wetlands range from growing *Phragmites australis* (common reed) for thatch and livestock feed, to collecting peat for heating and cooking fuel. Altered hydrologic regimes due to global climate change could further exacerbate encroachment of agricultural land use into wetlands.

The vulnerability and adaptation studies of the U.S. Country Studies Program are used to analyze where climate change impacts to agriculture may likewise impact wetland areas. Scenarios indicate higher temperatures and greater evapotranspiration altering the hydrologic regime such that freshwater wetlands are potentially vulnerable in Bulgaria, Czech Republic, and Russia, and that coastal wetlands are at risk in Estonia. Runoff is identified as a key hydrological parameter affecting wetland function. Since wetland losses may increase as a result of climate-change-induced impacts to agriculture, precautionary management options are reviewed, such as establishing buffer areas, promoting sustainable uses of wetlands, and restoration of farmed or mined wetland areas. These options may reduce the extent of negative agricultural impacts on wetlands due to global climate change.

1. Introduction

Naturally-occurring wetlands perform such functions as flood control, pollution filtration, nutrient recycling, sediment accretion, groundwater recharge and water supply, erosion control, and plant and wildlife preservation. Many rare and endangered species are dependent upon wetlands during all or part of their life cycle. The high biological productivity of wetlands has increasingly been recognized. According to Tiner (1984), freshwater wetlands are similar in net primary productivity to tropical rain forests, and salt marshes have even greater productivity (Figure 1). Historically, however, wetlands have been used for growing crops either by drainage, as with corn or potatoes, or by flood management, as with rice. Drainage of wet-

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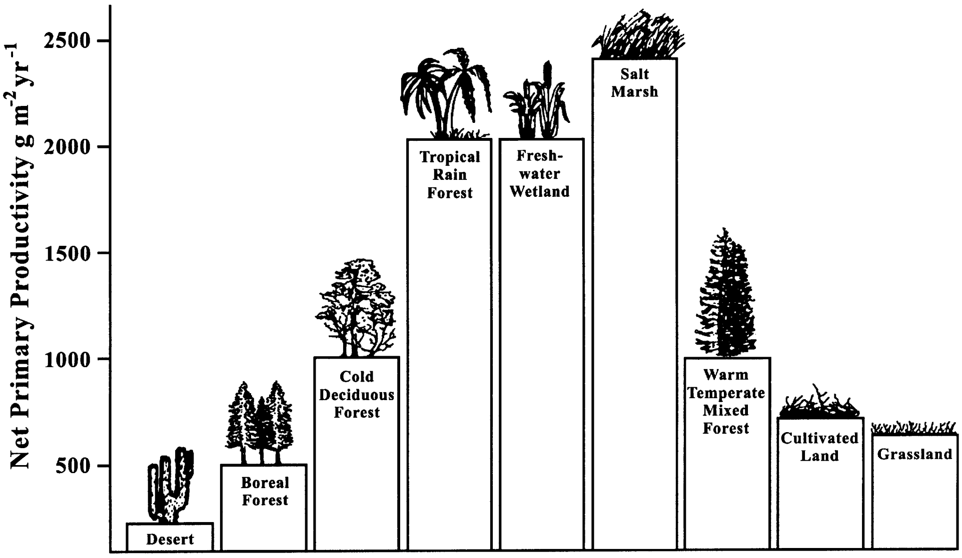

Figure 1. Relative productivity of wetland ecosystems in relation to other ecosystems (g m^{-2} yr^{-1}) (Source: Tiner, 1984).

lands for agricultural purposes is expected to continue, with losses concentrated where wetlands are most ubiquitous.

Shifts in agricultural land use due to climate change may bring increased infringement on already diminishing wetland areas. Reductions in runoff and increased evapotranspiration under changed climate conditions would also exacerbate the rate of wetland losses (IPCC, 1990, 1995). Under projected climate change scenarios, reduced runoff and precipitation, and alterations to the seasonal hydrological cycle, will decrease surface water recharge to inland wetlands and waterways (Mortsch, 1990). Losses to coastal wetlands will occur as sediment accretion or peat accumulation fails to keep pace with sea-level rise, or sufficient leeway no longer exists for marshes to shift landward due to man-made barriers. This paper examines potential climate change impacts on freshwater and tidal wetlands in Eastern Europe,* with emphasis on Bulgaria, Czech Republic, Estonia, and Russia.

* The unofficial regional group of Eastern European States of the United Nations includes Albania, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Georgia, Hungary, Latvia, Lithuania, Poland, Republic of Moldova, Romania, Russian Federation, Slovakia, Former Yugoslav Republic of Macedonia, and Ukraine. For this paper, Estonia and Slovenia are also included in Eastern Europe.

2. Wetlands Definition, Classification, and Distribution

Wetlands are habitats subject to periodic flooding of sufficient depth and duration for low oxygen conditions to prevail in the vegetative root zone during at least some portion of the growing season. Definitions of wetlands vary among scientists, and also among policy-makers, particularly when land-use issues are at stake. Criteria that comply with scientifically accredited definitions take into account, with varying emphases, three main parameters: wetland vegetation, soils and hydrology.

Criteria used to classify the presence of freshwater or coastal wetlands remain quite varied from region to region. In the United States the methodology used to designate jurisdictional wetland boundaries often varies according to differing local, state and national wetland regulations. Three parameters (vegetation, soils and hydrology) are currently used by the U.S. Fish & Wildlife Service and the U.S. Army Corps of Engineers (Corps) for delineating wetland boundaries under Corps jurisdiction (Cowardin et al., 1979; U.S. Army Corps of Engineers, 1987). This system has been adopted by the World Wildlife Fund for teaching purposes (Larson et al., 1989). A methodology for defining wetlands in agricultural lands developed by the U.S. Department of Agriculture, Natural Resources Conservation Service (formerly Soil Conservation Service) uses a two-parameter (soils and hydrology) approach; hydrophytic vegetation is replaced by crops.

2.1. MAPPING OF WETLANDS

Wetlands are found in moist habitats from the equator to the tundra, and can vary in size from prairie potholes less than 0.1 hectare in size in the Midwestern United States, to vast permafrost habitats found in Siberia. Global mapping of freshwater wetlands has been conducted at the Goddard Institute of Space Studies (GISS) (Figure 2a) (Matthews and Fung, 1987). The maps were produced primarily to estimate concentrations of methane flux from freshwater wetland sources, now recognized as a significant source of climate change (Harriss et al., 1988; Harriss and Frolking, 1992; IPCC, 1995). Matthews and Fung (1987) reported that according to their global database, approximately sixty percent of the global methane emissions come from peat-rich bogs that are concentrated along a 50–70 degrees North latitude swath. Matthews and Fung selected five categories to map freshwater wetland types: *forested bog, nonforested bog, forested swamp, nonforested swamp*, and *alluvial formations.*

Bogs are defined in the GISS database as peat- or organic-rich systems and can be either *forested* (e.g., spruces and firs) or *nonforested* (e.g., sphagnum moss and cranberry bogs). They are often formed from glacially-derived lakes and are found in the higher latitudes. *Swamps* are found in mineral soils with saturation or inundation during the growing season. *Forested* or *nonforested* swamps are found in the lower latitudes. *Alluvial formations* are found along riverine deltas.

As indicated in Figure 2a, major expanses of forested bogs are located across Europe, parts of Asia, and North America in the temperate zones. Scandanavia and Eastern Europe have especially large concentrations of forested bogs (49% and 27% of $1^\circ \times 1^\circ$ grid cells designated as forested bogs by Matthews and Fung (1987), respectively) (Figure 2b). Peatland, an inclusive term that describes both forested and nonforested bogs, is used by authors from Eastern European countries to designate peat- forming wetland ecosystems and is the term used herein where applicable.

2.2. WETLANDS AND AGRICULTURE

A few crops do not require land drainage and are grown under conditions where some wetland characteristics are maintained. Rice paddies are a major form of wetland farm practice in tropical and subtropical regions. In temperate regions, hay collected from wetlands is used for livestock feed. In Poland and other European countries, *Phragmites australis* reed beds are used for thatch, and in times when other preferred food stocks are not available, the reeds can be used for cattle fodder. In Romania, cellulose from harvested reed shoots is used in the production of paper (Szcepanska and Szczepanski, 1976). *Phragmites* propagates from underground rhizomes, developing dense perennial beds. In northern Poland, depending on local conditions, biomass of the aboveground *Phragmites* shoots ranges between 108 g m^{-2} and 1990 g m^{-2} (Pieczynska and Szczepanski, 1976). According to Kvet and Husak (1978) biomass for the above ground *Phragmites* shoots in a Czech fish pond ranges from 600 to 3700 g m^{-2}.

Wetlands have historically been drained by farmers for crop production through such practices as installation of underground drainage tiles, or more simply, rows of ditches. Unlike hydrophytic vegetation adapted to flooded soils for extensive periods during the growing season, most crops require aerobic soil conditions for adequate root growth.

European losses of wetlands to agriculture date back at least 2000 years, to Roman times. Significant expansion of farmland based on wetland drainage occurred from 1100 to 1300 AD in Eastern Europe along with expansion from colonization (Loomis and Connor, 1992). In Russia, large-scale organized wetland drainage for agriculture began under Peter the Great (Paavilainen and Päivänen, 1995). The rate of wetland loss, however, has accelerated dramatically in this century and this trend is expected to continue (Cowardin et al., 1979; Tiner, 1984). Percent of agricultural land comprised of drained soils was estimated by Green (1978) for Eastern European countries (Table I). According to Yablokov and Ostroumov (1991), drainage practices in the former Soviet Union were rapidly reducing the extent of peatlands there (estimated by Matthews (1993) to comprise approximately 30% of global freshwater wetlands).

Many governments, including the United States and the United Kingdom, have historically subsidized the drainage of wetlands to increase national crop yields

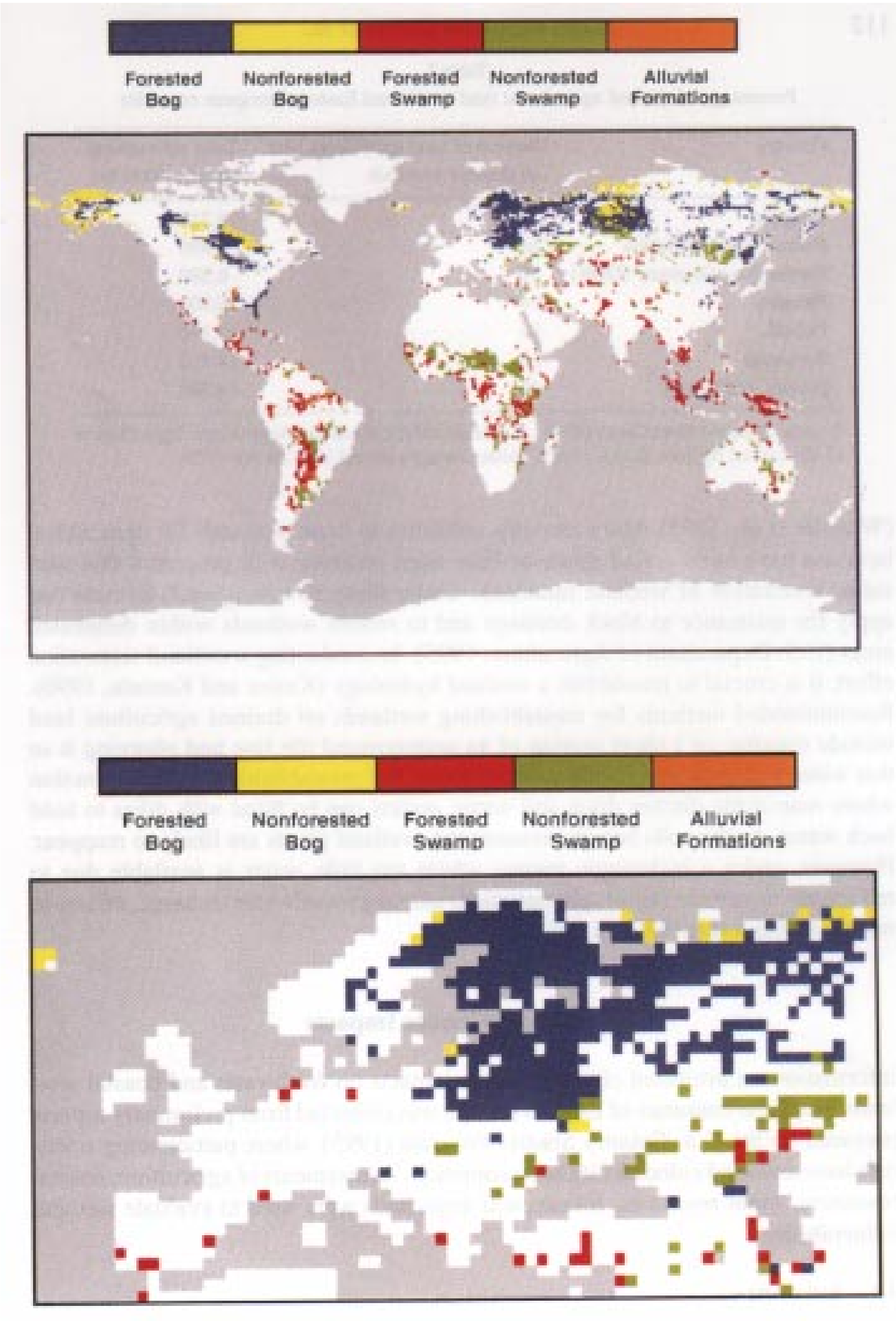

Figure 2. (a) Global distribution of freshwater wetland ecosystems from an integrated database indicating spatial dominance of wetland vegetation, hydric soils, and inundation in 1° × 1° grid cells, (b) Distribution of freshwater wetland ecosystems in Europe (Source: Matthews and Fung, 1987; NASA/GISS).

Table I
Percentage of drained agricultural land in selected Eastern European countries

Country	Percent of total agriculture land on drained wetlands	Total agricultural land (× 1000 ha)
Bulgaria	3	6,210
Former Czechoslovakia	16	6,950
Former East Germany (DDR)	27	6,280
Hungary	74	6,700
Poland	25	19,110
Romania	15	14,970
Former Yugoslavia	44	14,280

Source: Adapted from Green (1978) and AGROSTAT; Food and Agriculture Organization of the United Nations (FAO, 1993). Values for agricultural land are for 1978.

(Wheeler et al., 1995). More recently, subsidies to drain wetlands for agricultural land use have been scaled down or have been reversed with programs that subsidize restoration of wetland functions. Under these new programs, farmers can apply for assistance to block drainage and to restore wetlands within delineated areas (U.S. Department of Agriculture, 1995). In conducting a wetland restoration effort, it is crucial to reestablish a wetland hydrology (Kusler and Kentula, 1990). Recommended methods for reestablishing wetlands on drained agriculture land include digging up a short section of an underground tile line and plugging it so that water will back up into the wetland basin. For reestablishing wetland function where man-made ditches drain soil water, outlets can be filled with dikes to hold back water. As the soils become resaturated, wetland plants are likely to reappear. However, under a hydrologic regime where too little water is available due to reductions in surface runoff, precipitation, and/or groundwater recharge, efforts to restore wetland function will fail.

3. Climate Change Impacts

Information on projected climate change impacts on freshwater and coastal wetlands in several countries of Eastern Europe was collected from preliminary reports prepared for the U.S. Country Studies Program (1995), where participating scientists have assessed vulnerability and adaptation. Assessments of agriculture, coastal resources, water resources, forests, and grasslands were used to evaluate wetland vulnerability.

3.1. BULGARIA

Vulnerability assessments for forests and agriculture have been conducted for Bulgaria by applying doubled atmospheric carbon dioxide ($2 \times CO_2$) climate change

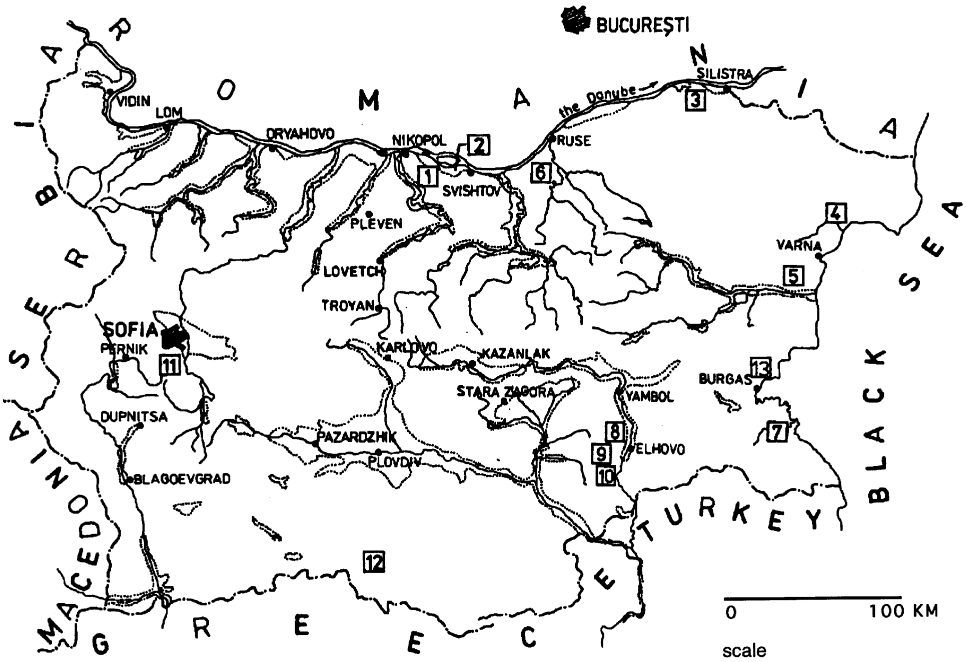

Figure 3. National parks and reserves in Bulgaria (Source: Grozev, personal communication).

scenarios for three global climate models (GCMs). These changes are projected to occur in the latter part of the next century. Preliminary studies using the Canadian Climate Centre (CCC), GISS, and Geophysical Fluid Dynamics Laboratory (GFDL) GCMs indicate that the cool temperate moist forests of Northern Bulgaria may undergo conversion to warm temperate dry forest (Raev et al., 1995). For the agricultural sector, influence of climate change on grain yield of the two main crops cultivated in Bulgaria, maize and winter wheat, was assessed using the Decision Support System for Agrotechnology Transfer (DSSAT) Version 2.1 (IBSNAT, 1989). Yields decreased under the higher temperature and lower precipitation of the scenarios tested.

Thirteen national parks and reserves in Bulgaria, some 0.06% (7049 hectares) of the country's total area, are protected by national and/or international conventions (Table II, Figure 3). The Srebarna Reserve, first established in 1955, was listed in 1973 under the Convention on Wetlands of International Importance Especially as Waterfowl Habitat (Ramsar Convention). In 1983 the reserve was further designated as a UNESCO World Heritage Site; only 90 particularly valuable areas are internationally recognized in this category (Lean et al., 1990). The 750-hectare site lies in the Danube River basin, in Northeastern Bulgaria, near the city of Silistra (Figure 3, #3) and supports 167 avian species including the Dalmatian pelican (*Pelicanus crispus*).

Table II
Protected national parks and reserves in Bulgaria

No[a]	Name	Area (ha)	Year established
1.	Stariat Dub Reserve	71.8	1971
2.	Persinski Blata Reserve	385.2	1981
3.	Srebarna Biosphere Reserve	750.0	1955
4.	Baltata Reserve	197.7	1962
5.	Kamtchia Biosphere Reserve	842.0	1951
6.	Rusenski Lom National Park	2227.0	1970
7.	Ropotamo National Park		1962
	a. Arkutino Reserve	96.6	1940
	b. Vodni Lilii Reserve	13.6	1962
8.	Gorna Toptchia Reserve	100.0	1951
9.	Dolna Toptchia Reserve	462.8	1960
10.	Balabana Reserve	67.0	1960
11.	Torfeno Branishte Reserve	782.8	1935
12.	Amzovo Reserve	0.3	1968
13.	Atanasovsko Lake Reserve	1050.0	1980
	TOTAL AREA	7046.8	

[a] Numbers refer to locations of protected areas mapped in Figure 3.

An analysis was conducted of potential future temperature and precipitation conditions that may prevail at the Srebarna reserve as projected by several of the GCMs. Temperature trends indicate annual average warming of 4.0°–7.6 °C under the three 2 × CO_2 equilibrium scenarios (Table IIIa). The most extreme is found with the UKMO scenario under summer conditions, with an 8.3 °C change. The least severe change (3.4 °C) is for summer temperatures under the GISS scenario.

The GISS transient climate change scenario, which projects the effects of gradually increasing CO_2 and other greenhouse gases over the next century, indicates that average annual temperature increases more than 2 °C by year 2030 (Table IIIb). By 2050 all seasons had a more than 3.0 °C average increase in temperature.

Trends for precipitation levels were less clear. Precipitation decreased for all three 2 × CO_2 GCM scenarios during the summer months, ranging from –9% (GISS) to –67% (GFDL)

(Table IIIc). It should be noted that under the GFDL simulated current climate (1 × CO_2), the summer precipitation was low (0.2 mm/day); thus, 67% represents a very small decrease in actual precipitation amount. Winter months showed an increase in precipitation for the three GCM equilibrium scenarios. Annual projections also showed an overall increase in precipitation. The GISS transient scenario tended to be drier than the equilibrium scenarios on an annual basis with reversed seasonal changes (Table IIId).

Table III

Climate change scenarios for the Srebarna Biosphere Reserve, Bulgaria

a.	Average temperature change (°C), $2 \times CO_2$		
Model	Summer[a]	Winter[b]	Annual
GISS	3.4	4.7	4.4
GFDL	3.9	4.1	4.0
UKMO	8.3	7.1	7.6
b.	Average temperature change (°C), GISS transient climate change scenario		
Year	Summer	Winter	Annual
2010	1.8	0.7	1.2
2030	2.2	1.6	2.2
2050	4.2	3.1	3.8
c.	Average precipitation change (%), $2 \times CO_2$		
Model	Summer	Winter	Annual
GISS	–9	6	5
GFDL	–67	33	22
UKMO	–13	9	2
d.	Average precipitation change (%), GISS transient climate change scenario		
Year	Summer	Winter	Annual
2010	7	–5	–6
2030	0	–8	–8
2050	54	–13	1

Sources: GISS (Hansen et al., 1984); GFDL (Wetherald and Manabe, 1986); UKMO, United Kingdom Meteorological Office (Wilson and Mitchell, 1987).
[a] Summer refers to the three months June, July, and August.
[b] Winter refers to the three months December, January, and February.

Such changes in temperature and precipitation would be likely to induce altered hydrologic regimes and lead to associated impacts on the bird populations that the Srebarna reserve has been established to protect.

3.2. THE CZECH REPUBLIC

In the Czech Republic, wetlands provide feeding grounds for fish in a long-established and highly productive aquaculture system. Carp (*Cyprinus carpio*) is the dominant species in shallow fish ponds. Surface area of the fish ponds range from several hundreds of square meters to several square kilometers. The maximum surface depth rarely exceeds 4 meters and more commonly does not exceed 1.5 meters (Hejný and Kvet, 1978). With the formation of the fish ponds, the hydrologic regime has not been radically altered, but rather has been modified to allow aquaculture farming (Hillel, 1992). Unlike other Eastern European agricultural systems, Czech wetlands are more integrated into the food supply system (Joseph Larson and Edward Hollis, personal communication). Thus in the former Czechoslovakia drained wetlands accounted for only sixteen percent of its croplands compared to other countries of Eastern Europe as of 1978 (Table I). In contrast, according to Green (1978), Hungary has drained 74% of its wetlands for agriculture. While the construction of the fish ponds may have at one time been a reaction to flooded land unsuitable for crops, a climate-induced loss of the water resources needed to maintain the fish ponds would disrupt a currently viable agroecosystem. On the other hand, longer frost-free periods might extend the seasonal use of the fish ponds.

The Czech Republic's Country Study Report estimates changes for three climate change scenarios and models for four selected watersheds varying in size from 100 to 5100 km^2 (Czech Republic Country Study, 1995). With no change in precipitation, 10–30% decreases in runoff are estimated with temperature increases of 2° to $4\,^\circ C$. The least favorable scenario is a 5% decrease in precipitation with a concurrent increase in temperature. Under such a scenario the resulting runoff would decrease by as much as 50%. Such reductions in precipitation would lower water levels in the impounded lakes used for fish farming, thus significantly reducing protein resources of the country. Of course, the timing and frequency of changes of precipitation events will also influence resulting runoff. Under climate change, the growing season is likely to lengthen, i.e., the current April-to-September growing season may extend to March-to-October.

3.3. ESTONIA

Estonia is located along the Baltic Sea and the Gulf of Finland. Low-lying coastal areas cover approximately twenty percent of the country, and thus account for Estonia's vulnerability to impacts from sea-level rise associated with climate change (Kont et al., 1996). The low-lying coastal regions include reed beds, alvars (pasture lands), wooded meadows, dunes, lagoons and drained fields. Inland regions include 907,000 hectares of peatlands: 9% (84,000 hectares) has been drained for agriculture and 50% (463,000 hectares) has been drained for forestry (Paavilainen and Päivänen, 1995). As part of the Estonian Country Study on Vulnerability and Adaptation to Climate Change, scientists are calculating climate change impacts in regard to land loss, rate of peat accumulation, changes in pH values, groundwater supply and recharge, nutrient supplies, and saltwater intrusions (Kont et al., 1996). Special attention is given to the low-lying coastal wetlands and floodplains, specifically the West-Estonian Plain and the West-Estonian Archipelago.

3.4. RUSSIA

One third of the world's peatlands are located in both European and Asian parts of Russia (Izrael and Avdjushin, 1995). Harvested peat is used to fuel power stations designed to accommodate the high water content of the fuel, since even after it is drained and solidified peat can still contain 70–95% water (Singer, 1981). The countries of the former U.S.S.R. account for approximately 95% of the peat mining world-wide with most of it utilized for electricity (Mitsch and Gosselink, 1993). In Russia alone, 80 million tons of peat are collected annually. This quantity accounts for approximately four percent of Russia's total electrical output (Babcock and Wilcox, 1992).

Peatland area in Russia drained for forestry, including silviculture, is estimated at 3.8 million hectares (Paavilainen and Päivänen, 1995). The position of the water table regulates the extent of oxygen penetration into the peat profile. By altering the hydrologic regime through construction of drainage ditches an aerobic layer slowly deepens to form a root zone conducive to tree growth. Such draining activities in bogs increase the decomposition rate of the peat which in turn leads to increased fluxes of CO_2 to the atmosphere.

Climate warming will affect the functioning of the bog ecosystem in Russia and elsewhere. Carbon in anaerobic peat is not likely to be freed by decomposition as long as cool, wet, acid conditions dominate (Crum, 1988). But if climate becomes warmer and drier, peat accumulation rates will decrease, and eventually the decay of peat could outpace accumulation. A 1 cm break-down per year of the boreal peat layer globally would result in a release of about 2Gt C yr^{-1}, or more than a third of the current annual release of carbon to the atmosphere via fossil fuel combustion (Crum, 1988).

As peatlands in Russia have been subjected to large-scale manipulation for agriculture, silviculture and peat mining, it is important to ascertain if the peatlands are a net carbon sink or source. As part of the U.S. Country Studies Program, the rate of peat loss has been evaluated by the Russian Federation (Izrael and Avdjushin, 1995). On the sink side, research is presently being conducted by the State Hydrological Institute on methods for tracking peat accumulation over time. A previous estimate for the rate of peat accumulation for a sphagnum-pine bog community in Russia was 43 g C m^{-2} yr^{-1}; this estimate was derived from flux measurements of carbon (Mitsch and Wu, 1995).

4. Policy Implications and Limitations

Wetland protection is likely to become increasingly crucial under global climate change. Climate change scenarios indicate that both drought and flood conditions may occur with increased frequency in the near future (IPCC, 1990, 1995). Under drought conditions wetlands soil, with its inherently high water-holding capacity, tends to retain water for longer than drained soil. In addition many hydrophytic plant species are able to sustain droughts. Farmers who have preserved or restored wetlands may therefore benefit from the retained water source during drought years. In times of excess precipitation, wetland areas hold water like a sponge, thus preventing flooding of adjacent fields and crop losses (Teal and Teal, 1969). Inland wetlands may store water that is gradually released to downstream areas, thus lowering flood peaks. Mitch and Wu (1995) emphasize further that wetlands may function in climate stabilization since forested bogs may provide a significant sink for carbon.

Policies that promote protection of wetlands and establishment of buffer zones beyond the delineated boundaries of wetlands will allow vegetative communities to shift in reaction to wetter or drier periods. Providing buffer zones may also keep coastal ecosystem function intact during sea-level rise. Promoting buffer zones along streams and riverbanks to absorb floodwaters will aid in reducing potential impacts from climate change. Thus wetland policies that take into account both protection and remediation may be recommended as appropriate preparatory measures for projected climate change (IPCC, 1995).

However, tremendous variation currently exists both between and within countries in regard to policies governing use of wetlands and their adjacent areas. Losses continue even in protected parks and reserves (Hollis et al., 1988). International agreements that promote wetland protection include the Ramsar Convention under which 192 wetland reserves have been established in 29 nations (Goriup, 1990). However, this covers less than 0.25% of the world's wetland resources. The policies of the former Soviet Union protected two percent of its wetlands resources (Yablokov and Ostroumov, 1991). The United States restricts construction activities within or adjacent to coastal and freshwater wetlands through regulatory guidelines. However few nations have policies in place that protect wetlands from agricultural use. This may be a critical element in policies appropriate under changing climate conditions.

5. Conclusions

In Eastern Europe drained wetlands form a significant percentage of the agricultural lands of many countries. The extent of future wetland losses will depend on land-use policies, socioeconomic conditions, and vulnerability to climate change. Currently, wetland losses continue even in protected parks and bioreserves. Losses may be even more difficult to contain under projected climate change scenarios. Wetlands are especially beneficial under extreme drought or flood conditions for their ability to retain water, reduce runoff, filter sediments, and provide water purification.

The greatest impact to wetlands are from changes to hydrologic regimes. Higher temperatures accompanied by either lower precipitation or greater precipitation that is not enough to compensate for increased evapotranspiration will change the hydrologic regime enough to damage wetland functions.

Policies that protect wetlands will also assist countries vulnerable to climate change impacts. Participating countries in the U.S. Country Studies Program can use the information collected on vulnerability and adaptation from several sectors, including agriculture, forests, water, and coastal resources, to evaluate impacts to wetlands. Scenarios should continue to be tested to learn how agriculture and wetlands may interact in the future.

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